

The non-invasive functional tissue characterization for arteriosclerosis by artery wall motion analysis with time series high-speed echo images and continuous Sphygmomanometer

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Abstract- The evaluation method of arteriosclerosis has been established, but most of them are invasive way. In late years, non-invasive diagnostic method for arteriosclerosis can be done by the diagnosis with high resolution echography. However, even this new diagnostic method can not diagnose until beginning the morphologic changes of the arteries by stenosis. There is little value even if it could be detected the arteriosclerosis after the stenosis of the arteries have progressed.

And we thought that it should be non-invasive method for evaluating the arteriosclerosis. We introduced a idea of rheological dynamics into analysis. For example the cross-section area of young elastic artery may expand quick and wide and old one dose narrow and slow expansion by blood pressure. We call it functional tissue characterization, and investigated common carotid artery of about 160 persons.

In this way we diagnosed the arteriosclerosis by aging quantitatively by some parameters by the nonlinear pressure and area of common carotid artery curve. Furthermore, we were able to separate hypertension group and a physically normal group quantitatively as a result of having evaluated the arteriosclerosis from various vascular disease.

Keywords- arteriosclerosis, non-invasive, functional tissue characterization, echography

I. Introduction

The incidence of circulatory diseases caused by arteriosclerosis is increasing in Japan. Cerebrovascular and heart diseases account for about one third of fatalities in Japan, and so they clearly kill more people than cancer does. Nonetheless, there are currently no established methods to assess arteriosclerosis. Due to the recent development of high-resolution ultrasound B-mode images, it has become possible to non-invasively diagnose arteriosclerosis. However, even newly developed diagnostic methods only examine the morphology of arteries, and since they can not quantitatively assess arteriosclerosis, this disease can only be diagnosed when the morphology of arterial walls changes.

Consequently, by the time arterial walls have thickened or calcified, arteriosclerosis has already been established. Therefore, to prevent the onset of diseases caused by arteriosclerosis, we have to

diagnose arteriosclerosis before appearance of the morphological changes. Thus, we thought that for a diagnostic method of arteriosclerosis to be truly useful in preventing diseases, then the functional characteristics of the vascular walls must be quantitatively assessed. Furthermore, from the viewpoint of preventive medicine, this diagnostic method should be non-invasive, and capable of assessing arteriosclerosis which is undetectable by the existing ultrasound B-mode images.

The elderly and hypertensive patients can be differentiated from the healthy individuals by tissue characterization [1].

II. Methods

Shifts in the wall of the common carotid artery and their velocity were calculated from ultrasound B-mode images. Also, by determining the blood pressure, the motion of the wall of the common carotid artery was analyzed. The resultant nonlinear characteristics were statistically and dynamically analyzed to identify unique findings and properties indicative of diseases that could cause arteriosclerosis.

Data acquisition

By using high-speed digital subtraction echography (EUB 565S, Hitachi Medico Ltd.) equipped with a linear 7.5-MHz probe, a B-mode image of the cross-section of the short-axis of the common carotid artery and its pulse wave were synchronized, simultaneously displayed on the same screen, and recorded.

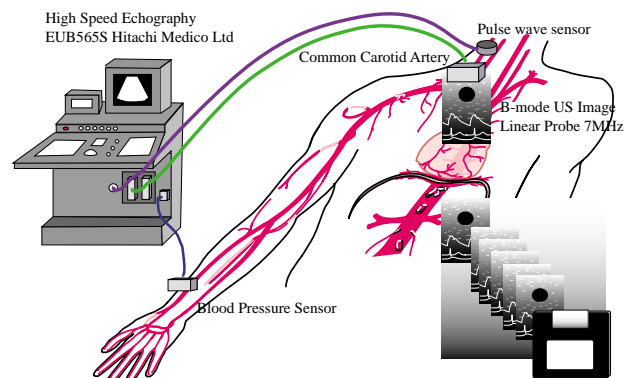


Fig.1 B-mode image of common carotid artery and blood pressure synchronized recorded on the same screen.

The blood pressure of the common carotid artery was non-

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invasively measured by tonometry using a continuous sphygmomanometer (JENTOW Japan Colin Ltd.), and the pulse wave of the common carotid artery was determined by a carotid artery pulse wave sensor, taking into account the time gap between the common carotid artery and the radial artery. Figure 1 shows the data acquisition system. Cross-sections (B-mode ultrasound images) of the common carotid artery were temporarily stored in the graphic memory of EUB 565S, and transferred to a magnetic optic disk (MO disk). The cross-sectional images of the common carotid artery were taken per pulse at a frame rate of 63/second. To incorporate these continuous images into a computer, they were converted to TIFF files.

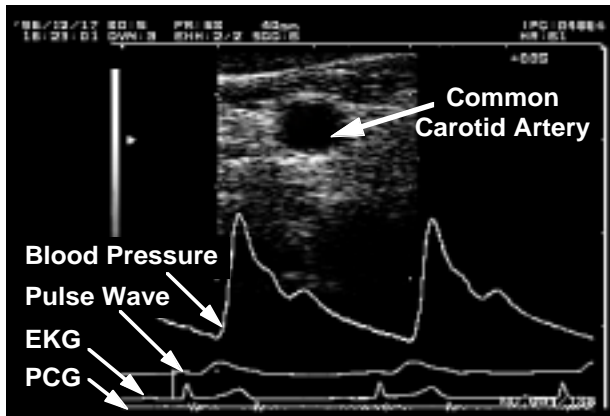


Fig.2. B-mode image of common carotid artery and blood pressure synchronized recorded on the same screen.

Image processing

The gradation of images was set at 8 bits (256 gradations). The continuous images of cross-sectional area of the common carotid artery were measured by image processing. The pulse waves recorded on ultrasound images were extracted and quantified. Since the blood pressure was continuously measured at the radial artery, by utilizing the pulse wave of the common carotid artery, the time gap in the pulse wave between the common carotid artery and radial artery was used to determine the blood pressure of the common carotid artery.

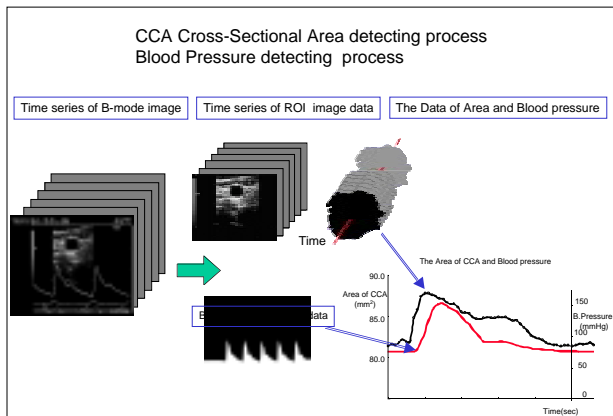


Fig.3. Regions of interest (ROI) were extracted under the same image processing conditions.

The time-series data obtained by this set of image processing were continuous blood pressure, cross-sectional area of the common carotid artery (S). These data were synchronized and superimposed (Fig. 3).

Patients of analysis

13 to 89 years (mean: 57.4 years) with various conditions were the subjects (including 37 healthy individuals, 68 obese individuals, 76 hypertensive patients, 35 diabetic patients, 30 patients with hyperlipidemia, 14 patients with chronic renal failure, 12 patients with cerebral infarction, and 6 patients with old myocardial infarction). The results of clinical laboratory tests on these subjects were also recorded, and their relationships with the functional characteristics of the wall of the common carotid artery were statistically analyzed. Nonetheless, patients with cardiac arrhythmia were excluded from the present study.

Dynamic movement of the common carotid artery

The relationship between the cross-sectional area of the common carotid artery and blood pressure is plotted in Fig.4 which clearly shows that the movement of the vascular wall is nonlinear.

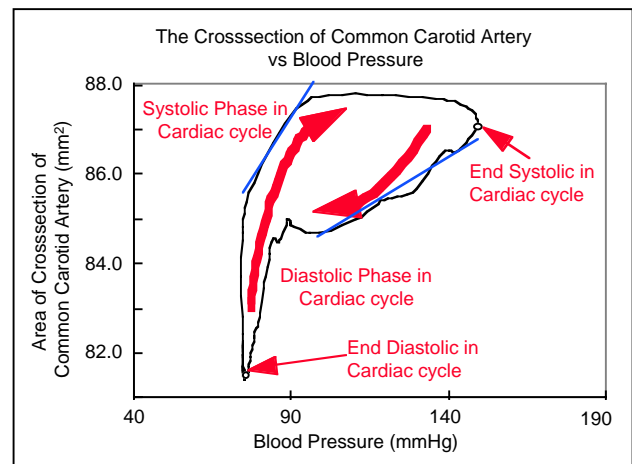


Fig.4. P-S curve (P: Blood pressure, S: Cross-sectional area of the common carotid artery)

III. Results

By using high-speed digital subtraction echography (Hs-DSE), we can now measure the contraction velocity of the common carotid artery and assess small shifts in the artery [1]. We measure the functional elasticity of the arteries to diagnose arteriosclerosis, analyzing not only the shift and velocity of the wall of the common carotid artery, but also its blood pressure. Previously, we quantified the viscoelasticity of the wall of the common carotid artery, and evaluated its viscous and elastic components [2]. The functional parameters (stiffness and viscosity) were determined from the P-V curve (blood pressure-carotid artery expansion velocity

curves) of each subject, and significant differences were seen between the young and the elderly not only in the curve pattern, but also in the curve area (which represents energy) [2], [3], [4].

In the present study, the cross-sectional area of the common carotid artery was measured chronologically, and changes in the cross-sectional area caused by blood pressure were analyzed. We analyzed the characteristic movement of the common carotid artery by plotting the blood pressure and cross-sectional area of the common carotid artery on plane coordinates. Since the characteristic movements of the common carotid artery were nonlinear, we were able to extract various parameters. We then statistically analyzed these parameters to develop a functional histological method for diagnosis of arteriosclerosis.

Dynamic parameters for statistical analysis

Beside the elastic coefficient, the compliance (which is a dynamic parameter) was evaluated in preparation for later statistical analysis. We predicted that changes in the expansion and contraction of young arteries would be greater, and that the degree of these changes would decrease with age or by a disease. As shown in Fig. 5, compliance during the diastolic and systolic phases was defined as follows: Compliance = $(\Delta S/S)/\Delta P$

(ΔP : the difference of blood pressure, S: the cross-sectional area of the common carotid artery, ΔS : the difference of S)

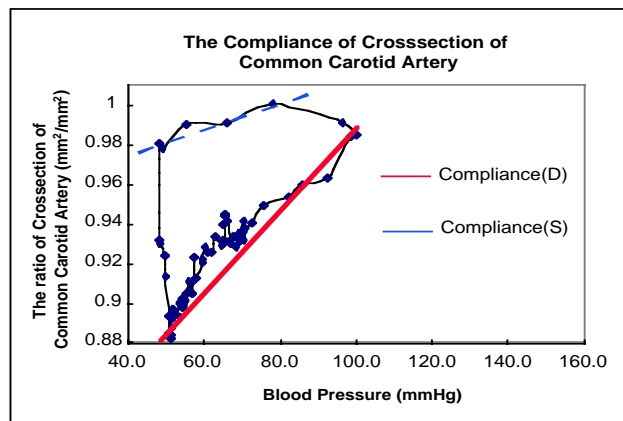


Fig. 5. The compliance during the diastolic and systolic phases, The cross-sectional area was standardized by its maximum value.

The effects of aging and disease on compliance were analyzed. As shown in Fig. 6, aging clearly affects compliance (D).

A rapid decrease in compliance was seen in people in their 30's and older, thus suggesting development of arteriosclerosis. The results showed that there were no significant differences in the value or tendency of compliance (D) between men and women.

Fig. 7 shows the average compliance of various subgroups. The figure clearly shows that the compliance of healthy individuals was larger. Nonetheless, there were no marked differences in the compliance among patients with various diseases.

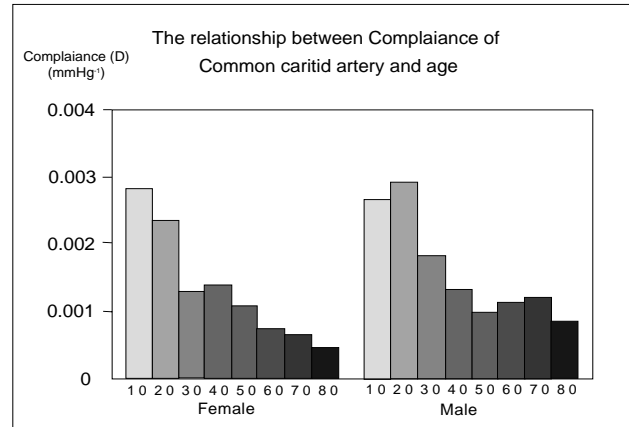


Fig. 6. The relationship between compliance and age.

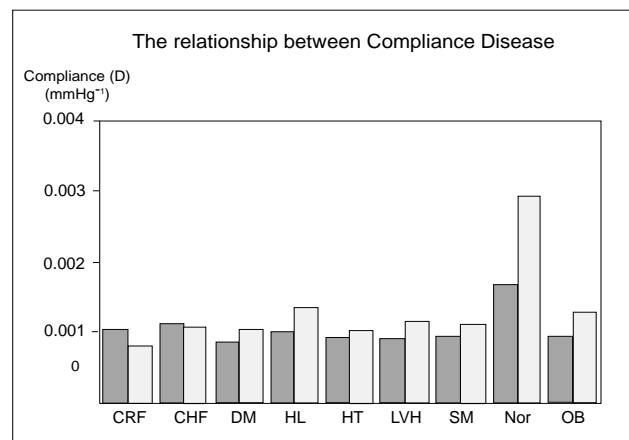


Fig. 7. The relationship between compliance and diseases.

By analyzing changes in the cross-sectional area of the common carotid artery, the effect of aging can be quantitatively assessed. However, although the healthy individuals and hypertensive patients could be differentiated by statistical analysis, the characteristics of arteriosclerosis among patients with various diseases could not be clarified.

IV. Discussion

The advantage of the present method, as in the echo-tracking method, when estimating the hardness of a vascular wall using reflected echography by measuring one-dimensional changes in the diameter of vessels, the vascular elasticity indicators, such as the stiffness parameter used by Hayashi et al., are often employed. Nonetheless [5], [6], [7], since the diameter of blood vessels is measured in one-dimension, measurements are difficult at some locations (e.g., the central axis of a target vessel may be outside of the measurement range due to factors such as respiration or pulsation). The blood vessels sometimes shifts parallel swinging motion.

Also, matters such as irregularity in expansion of the vascular walls, and motor components vertical to the vascular axis, must be

taken into account. The blood vessels expands eccentric wall motion.

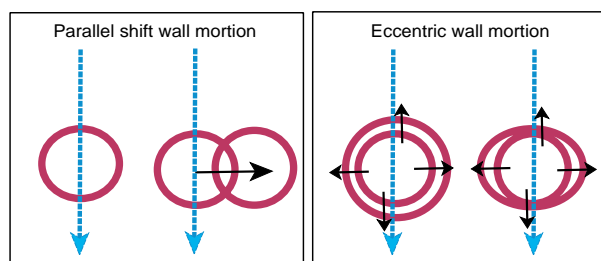


Fig. 8. The advantage of the present method compare to the echo-tracking method.

We found that the cross-sectional area of the common carotid artery and blood pressure were important parameters in a dynamic model of the common carotid artery. The present study showed that the common carotid artery changed with age, and the results of a multiple regression analysis including clinical laboratory tests clarified that there was a strong correlation between the age and compliance (C: inverse number of elastic coefficient):

$$C = 2.1 \times 10^{-3} - 2.71 \times 10^{-5} (\text{age}) + 1.38 \times 10^{-6} (\text{weight})$$

Multiple regression and principal component analyses showed a strong correlation between the vascular elasticity and age, thus suggesting that it would be possible to diagnose arteriosclerosis caused by aging. Also, of these parameters, the elasticity was shown to be able to differentiate between the hypertensive patients and healthy individuals[8].

V. Conclusions

The functional elements of the wall of the common carotid artery were analyzed as time-series image data by synchronizing them with the continuous pulse waves, using high-speed echography. Since the multidimensional data on arteriosclerosis are stored as simple generalized images on a single magnetic optic disk, its usefulness is only expected to expand in the future. Also, through the use of image processing, the displacement of the vascular wall and blood pressure were determined, and quantification of the functional characteristics of the vascular walls was performed.

The results of the present study showed that, based on the functional analysis of the vascular walls, arteriosclerosis, that is undetectable by the conventional ultrasound echography could be examined. When the elasticity of blood vessels is analyzed, the elastic properties of the vascular wall are generally assumed to be linear for simplifying the analysis, but in the present study, the non-linear nature of the elastic properties was quantified and actively evaluated to diagnose arteriosclerosis.

Although we were not able to concretely differentiate the pattern of arteriosclerosis in people with various diseases, we gathered important information. If this method is established, it may be

an one of the non-invasive diagnostic way for the tissue characterization for arteriosclerosis.

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